Case History

Queensland BHP Steel:
diagnosis of a fan bearing problem

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Queensland BHP Steel (QBHPS) operates a steel rolling mill that processes a range of commercial and spring-grade flats and rounds and deformed reinforcing bar for concrete. The natural gas fired billet reheat furnace can heat 70 tonnes of billet feed per hour to a rolling temperature of nominally 1150°C (2100°F). An overhung impeller-type combustion air fan (Figure 1) supplies up to 23,500 Normal cubic metres per hour (14,670 SCFM) of air through a recuperator to 51 burners. The 2940 rpm (49 Hz) fan is driven by a 1470 rpm (24.5 Hz), 110 kW induction motor through a matched set of 10 vee-belts. The 76mm (3 inch) diameter shaft is supported between the impeller and pulley in two double-row, spherical roller bearings with tapered bores and adapter sleeves. The 22217-K-C3 bearings are grease-lubricated and contained in standard plummer blocks.

The problem

The bearings have demonstrated poor reliability since original commissioning, with run lives varying from a few days to about nine months. The fan's operating speed is generally considered marginal for grease lubrication, and operating temperatures tend to be high. To monitor these temperatures, thermocouples were placed in contact with the bearing outer rings some years ago. They generally read around 50 to 60°C (120 to 140°F) but exceed this range when approaching failure (which can proceed to seizure).

Premature failures have been simply attributed to grease lubrication being unsuitable for the operating speed. Attempted corrective action, which primarily included higher performance greases and a more frequent regreasing program, have met with limited success.

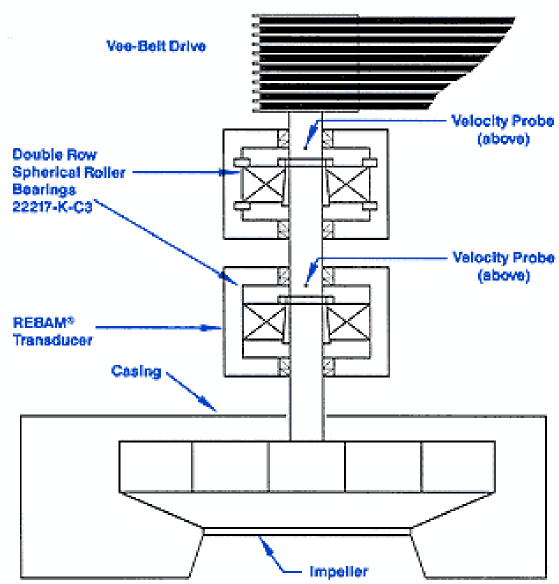

Figure 1
Queensland BHP Steel's overhung impeller-type combustion air fan.

Practically all bearings have displayed some degree of fretting damage to the outside of the outer ring. At times, damage was only minor and was generally considered to be of secondary importance to the high temperatures.

Data gathering

In late 1991, QBHPS and Rotor Dynamics Pty. Ltd. installed a Bently Nevada Trendmaster® 2000 condition monitoring system. QBHPS' primary objective was to improve the maintainability of equipment in the mill through a cost-effective, automatic system. The Trendmaster® 2000 System was offered as appropriate and was promoted by Bently Nevada based on:

- Safety—for monitoring points located in hazardous areas
- Reliability—of monitoring through permanently-installed transducers and automatic sampling
- Versatility—through a range of available transducers
- Cost-effectiveness—through low system cost and decreased manual labor requirements

Initially, one REBAM® (Rolling Element Bearing Activity Monitor) was installed to monitor the pulley end bearing. A stripped thread in the plummer block prevented installation of a second REBAM® to monitor the impeller end bearing.

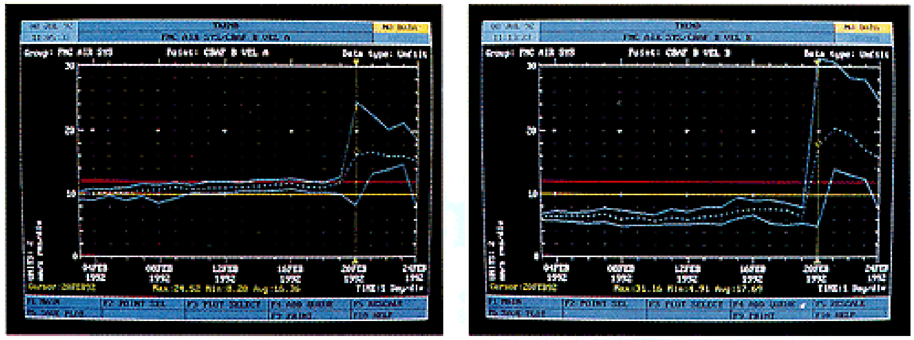

Figure 2
Trend plots made by the velocity transducers (left, A; right, B) showing a sudden increase in amplitude.

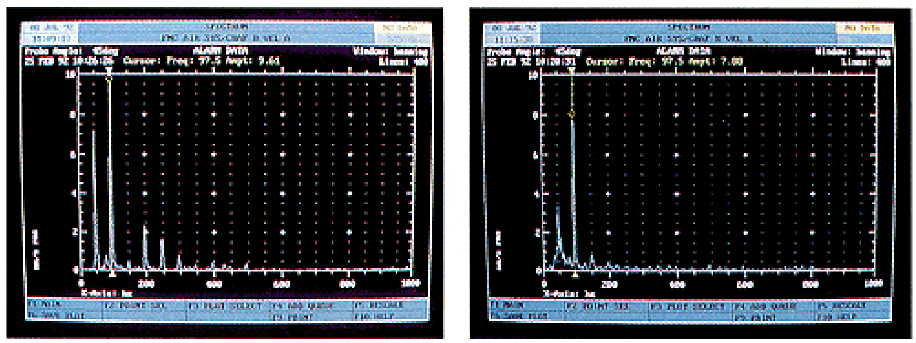

Figure 3
Spectrum plots made by the velocity transducers (left, A; right, B) showing a sizeable increase in energy at 2X shaft speed.

The signal from the pulley end bearing showed that the probe gap would steadily increase up to the time that the bearings were replaced due to uncontrolled operating temperatures. While plenty of energy was seen in the Spectrum at shaft rotating speed and its harmonics, it was not seen at the rolling element passage frequency as had clearly been the case with REBAMs installed in two other machines.

It was decided to relocate the REBAM® probe from the pulley end bearing where the loaded part of the outer ring was in the lower part of the plummer block making access difficult. The REBAM® probe was moved to the impeller end bearing and installed observing the part of the outer ring near where the reaction to the vee-belt tension would occur. The result was roughly the same as for the pulley end bearing: steadily increasing gap and energy at shaft rotating speed and its harmonics but nothing at the rolling element passage frequency. At that point, there was little doubt that the steady increase in probe gap was due to fretting between the outer ring of the bearing and the plummer block, but the temperature still seemed to be the most reliable indicator of bearing condition.

The pulley end bearing temperature was deemed to be uncontrollable for days preceding 25 January 1992, when the temperature reached an incredible 140°C (280°F). However, the bearing did not seize. Consultation with an expert from a bearing distributor confirmed that the internal clearances in both bearings had been permanently reduced. Even though the clearance of the pulley end bearing was difficult to measure, it was estimated to be no more than 30 μm (0.001 inch) as opposed to a nominal 120 μm (0.005 inch) for a new C3 bearing.

Permanent reduction in clearance occurs as a result of a volume change accompanying metallurgical phase transformations, mainly of retained austenite. This transformation commences at about 125°C (260°F) for many, but not all, standard bearings. In spite of the reduced clearance, the rollers, cages, and raceways showed no signs of spalling, pitting, lubrication failure, overload

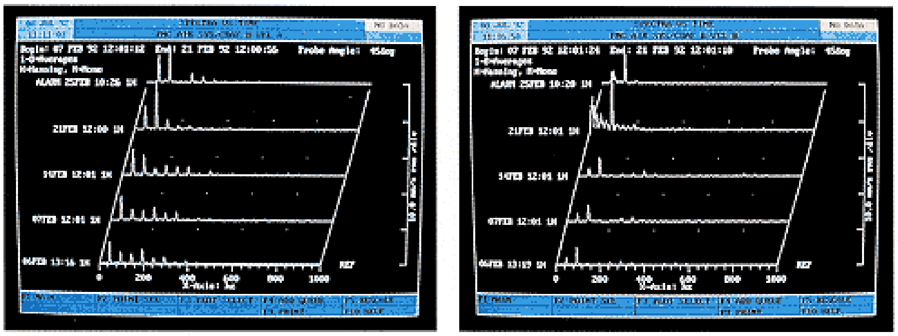

Figure 4
Spectra versus Time plots made by the velocity transducers (left, A; right, B) showing increasing energy at 2X shaft speed.

or abuse visible to the naked eye. Fretting damage to the outer rings was, however, present as usual.

A velocity transducer was installed on each plummer block and connected to the Trendmaster® 2000 System. The next temperature excursion was reported on 20 February 1992, the same day that both Trends made by the velocity transducers underwent a sudden increase in amplitude (Figure 2). In addition, the Spectra of the velocity transducer signals showed a sizeable increase in energy at 2X shaft speed (Figures 3-4). The maximum amplitudes of the velocity probe signals had been increasing slowly, but steadily, before the sudden increase in amplitude. The minimum amplitudes also changed but not as consistently as the maximum amplitudes.

The REBAM® on the impeller end bearing had shown its usual steadily-increasing gap but no sudden increase. The bearing temperatures did not stay out of control on this occasion, but, for some reason, they decreased again over several days. As they did, the velocity amplitudes also decreased somewhat. When the vibration levels decreased, the Spectra also changed, but the energy at 2X running speed was still significant. The Spectrum of the pulley end bearing signal started to show a broader band of frequencies above and below shaft speed.

The additional information captured by the Trendmaster® 2000 System, mainly from the velocity transducers, was correlated with temperature change information, the REBAM® gap trend and the condition of previously-failed bearings. This, in turn, alerted QBHPS to the possibility that there might be another reason for the high bearing temperatures than just the use of grease lubrication at the operating speed.

Many questions were unanswered, including: Why was the temperature increase sudden? Why was the velocity amplitude increase at first steady but later sudden? Why did the sudden temperature and velocity increases apparently coincide? Why did the subsequent gradual temperature and velocity decreases also apparently coincide? Why were bearings not showing obvious signs of seizure in spite of temperatures high enough to defeat any ordinary lubricant?

The main clues to the source of the problem were the suddenness of the vibration velocity amplitude increase and the strength of the Spectra at 2X shaft speed, both characteristics of nonlinear vibration and mechanical looseness. The amplitude jump phenomenon is usually described in terms of the running speed (or a multiple of running speed) passing through a fixed resonance of the nonlinear system, but it could equally result from a change in a resonant frequency of the system while the running speed remains constant. This is quite likely to have happened because fretting would radically alter the stiffness of the bearing support, making it very nonlinear as well.

Review of bearing application guidelines indicated the need for a tight fit over the outer ring of a bearing subjected to a load rotating relative to the outer ring. Where high speed fans are subject to out-of-balance forces due to dirt build-up, their bearing loads can be classified as rotating relative to the outer ring. While there was nothing wrong with the plummer blocks themselves, they were never designed for applications involving loads that rotate relative to the outer ring and did not provide the tight fit required.

After examination of the general shape of the frequency response curves for a second order oscillator with one degree of freedom and a quadratically increasing (nonlinear) stiffness term, it was feasible that some resonant frequencies of the system had decreased because of fretting between the bearing outer rings and the plummer blocks. At some stage, one of them passed through 2X running speed, initiating an amplitude jump in a sub-harmonic resonance. As the resonant frequencies continued to decrease, the resonant vibration amplitude gradually subsided.

The REBAM® probe signal did not undergo a sudden increase in amplitude along with the velocity probes, as it was already seeing as much motion as the entire bearing ring was allowed to exhibit. The REBAM® System is designed to detect small deflections in the outer ring of a bearing which is held in a fixed position relative to the probe tip. In this particular instance, the outer rings were not fixed in their housings. As a result, the entire impeller end bearing was moving relative to the REBAM® probe tip, which was seeing all this motion, driven by the unbalance of the fan. Without a solid mount for the outer ring, there was no support to allow the forces on the elements to deflect the target area; hence, no outer race roller component was seen. In contrast, the sudden amplitude increase measured by the velocity probes was attributed ►

to the fact that their measurement was relative to the earth's gravitational field. Therefore, they were sensitive to the motion generated by the additional flexing of the shaft as it entered resonance.

The high temperatures observed during resonance are attributed to high amplitude and high frequency impact and fretting (at 2X running speed) between the bearing outer rings and the plummer blocks.

Close inspection of the Spectrum of the pulley end velocity probe signal (Figure 3) showed that the broad band of frequencies above and below shaft speed contained small peaks. When they were first noticed, it was apparent that they were mostly multiples of approximately 10 Hz. The length of the vee-belts was approximately fives times the pitch circumference of the fan pulley, implying that the fundamental frequency of the belts was about 10 Hz. Thus, the broad band of frequencies around shaft speed could be confidently associated with a deterioration in vee-belt condition. The spacing between the small peaks later became somewhat less regular, and peaks appeared at other frequencies.

Conclusion

From the reliability and cost containment point of view, it was the quality of all the information that gradually became available that alerted QBHPS to the real significance of the fretting damage. Good problem solving depends on conscientious use of good information. There was a step improvement in the quality of the information available once the necessary transducers were installed and their signals sampled, processed and trended by fully-automatic systems such as the pre-existing process control computers and the new Trendmaster® 2000 System. If automation had not been employed, signal sampling would not have been done reliably enough to detect what was happening. Once the information was in hand, the rest was relatively easy.

Corrective action will include the design change of the bearing and housing arrangement, making the shaft stiffer and changing to a toothed-belt drive.■

***Editor's Note:** Nothing in this article constitutes a recommendation, explicit or implicit, by QBHPS that the Trendmaster 2000 System or any other similar system is appropriate for any application other than QBHPS' own applications.*

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Case History

Hydro Power: treating the source of a problem, not just a symptom

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This article demonstrates how the correct application of instrumentation and diagnostic procedures can highlight otherwise obscure underlying causes of machinery problems.

Electricorp Production is a business unit of the Electricity Corporation New Zealand Ltd., which generates 96 percent of New Zealand's electricity. Electricorp Production produces 75 percent of its electricity from 30 hydroelectric power stations. The North Island has 16 of these stations with a combined capacity of 1,585 MW.

Eight stations are located on the Waikato River, the longest river in New Zealand. Water is cascaded from one station to the next to extract as much of the Waikato's potential energy as possible. Waipapa Power Station, commissioned in 1961, is the 6th in line on the Waikato system. Waipapa has three 17 MW Kaplan turbine type machines which rotate at 125 rpm. Figure 1 shows a simplified machine cross-section.